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Research Report

Total Carotenoid, Anthocyanin, and Sugar Contents in Sliced or Whole Purple (cv. BetaSweet) and Orange Carrots during 4-week Cold Storage

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Abstract. Minimally processed carrot products in finger or coin shapes are increasingly popular due to their convenience. The 'BetaSweet' carrot is a purple carrot with a high carotenoid and anthocyanin content, sweet taste, and juicy, crisp texture. This study was performed to investigate the changes in carotenoid, anthocyanin, and sugar of the sliced purple and an orange carrot during 4 weeks of cold storage at 2℃ or 4℃, simulating the transportation and marketing period. The purple carrot contained about 200-230 $\mu g \cdot g^{-1}$ fresh weight total carotenoid and there was a slight decrease in the total carotenoid content during the 4-week period at both temperatures. Anthocyanin and total sugar contents were about 400-500 $\mu g \cdot g^{-1}$ and 70 $mg \cdot g^{-1}$ fresh weight, respectively and did not change significantly at either temperature. The orange carrots, tested for comparison, contained about 100 $\mu g \cdot g^{-1}$ total carotenoid and about 60 $mg \cdot g^{-1}$ fresh weight total sugar, and showed similar trend as the purple carrots during cold storage. Transfer from 2℃ to 4℃ at 2 weeks did not show significant changes in any of the parameters. Sliced carrots had about 10% to 15% less carotenoid content as compared to whole carrots, probably due to wound damage and the oxidation process. The content of nutritional compounds of the purple carrots harvested during April and June was similar to that obtained throughout the season, demonstrating that consistent quality products could be produced. Our study confirmed that the changes in quality of sliced purple carrots were minimal or negligible during the commercial marketing period of 2 weeks, if the product was handled and displayed at 4℃ or below.

***Additional key words*:** harvest, marketing period, minimally processed, packing, quality

Introduction

Fruits and vegetables are rich sources of various phytonutrients, many of which have antioxidant properties. In addition to the well-known antioxidants, vitamins C and E, and β-carotene, fruits and vegetables contain other phytonutrients which significantly contribute to antioxidant activity and other health benefits (Alasalvar et al., 2005; Prior et al., 1998). Among vegetables, carrots are consumed mainly for their pleasant flavor and perceived health benefits related to their β-carotene, vitamins, minerals, and dietary fiber (Alasalvar et al., 2001). Among 38 other fruits and vegetables, carrots have been ranked 10th in terms of their nutritional value and 7th for their contribution to human health (Ensminger and Konlande, 1995).

The purple 'BetaSweet' carrot is a new type of carrot developed in 1998 at our Center and contains high levels of anthocyanins and carotenes. The purple carrots have a unique dark maroon color from the skin to half way to the center, and a dark orange color at the pith of the root. When the purple carrot is sliced into a coin shape, it shows a beautiful purple ring with an orange center. It is popular among consumers because of its unique color and juicy, sweet flavor, in addition to its health benefits from the anthocyanins and carotenes. The purple carrot contained about 40% higher β-carotene than an orange carrot and about 400-800 ppm anthocyanin compounds in our analysis performed during the breeding process (Lazcano, 1999).

Provitamin A carotenoids are a major source of dietary vitamin A in a large proportion of the world's population and β-carotene is the most common provitamin A carotenoid. Carotenoids are also beneficial in helping to prevent major health problems such as cancer, cardiovascular/coronary heart diseases, and other diseases, due to their antioxidant activity (Yeum and Russell, 2002). Anthocyanins are well-known natural colorants, which provide a bright red color to many

crops and foods. In addition to the colorant properties, they have a possible role in reducing the risk of coronary heart disease, cancer, and stroke, and an anti inflammatory effect (Wrolstad, 2004).

After harvesting and processing, nearly all crops, including carrots, lose their nutritional value from the time they were harvested. This is mainly due to the loss of nutritional compounds such as sugars, vitamins, carotenoids, and anthocyanins. Also, undesirable bitterness and an oxidized flavor may develop in carrots during processing and storage, if they are subjected to unfavorable environments (Yen et al., 2008).

Recently, the purple carrot has been packaged as a sliced carrot and has become popular because of its convenience without further cleaning and slicing. For marketing of the purple carrot, quality assurance is critical with regard to nutritional content. Ensuring the quality of the raw carrots before processing is a key point that dictates the quality of the processed carrot, in addition to any changes after processing.

By determining the changes in nutritional compounds during cold storage and marketing, we will provide critical information regarding this carrot to producers, processors, and consumer. Finally, the consumer will get the ultimate benefit of consuming a quality vegetable with higher health benefits. The objectives of this research were, first, the investigation of the bioactive compounds such as carotenoids, anthocyanins, and sugars in whole and sliced processed carrots during cold storage and, second, the compare of changes in these compounds in the whole purple carrot grown in South Texas.

Materials and Methods

Plant Materials

The whole or sliced purple 'BetaSweet' and orange 'Envy' carrots were supplied from a produce company at Edinburg, TX in March, 2008. The carrots were harvested, washed, and sliced at the company's facility. For the storage study, all carrots were harvested on same mature stage. Each of two types of carrots (purple or orange) and two configurations (sliced or whole) were used. Sliced carrots were cut 5 mm thick horizontally. For the harvest date study based on maturity, whole purple carrots were harvested bi-weekly between April and June. They were shipped by the day after harvest and processed upon arrival for the experiment, without storage procedures.

Storage Condition

About 300 g of sliced or 5 roots of whole carrots were packaged in a biaxial oriented polypropylene bag (20 × 15 cm, 0.03 mm thickness) with an antifogging layer. The typical values of water vapor and oxygen transfer rates for the bag were 0.32 and 95 g/645 cm^2 for 24 h, respectively. Each treatment had three bags as an experimental unit for the sliced or whole carrots, respectively.

Three temperature treatments were studies during storage. The carrot samples were stored at continuous 2℃ storage for 4 weeks, continuous 4℃ storage for 4 weeks, or at 2℃ for 2 weeks then transferred to 4℃ for an additional 2 weeks. The storage chambers were maintained at 90-95% relative humidity.

Total Carotenoid and Anthocyanin Content

All carrot samples in bags or as whole root were initially blended with 1% hydrochloric acid (1:1, w/v) using a home mixer, to protect anthocyanin from oxidation and to obtain uniform sub-samples. Duplicate sub-samples were taken from the homogenized slurry of carrots.

For extraction of carotenoids, a sample of approximately 5-g slurry was taken and finely homogenized with 30 mL acetone using a Polytron PT 10-35 (Kinematca, AG, Switzerland). The homogenate was washed with acetone on filter paper until the plant material became colorless. The final volume was adjusted to 100 mL. The extract was mixed well, and 40 mL was placed in a 50 mL glass tube and kept at -70℃. Three milliliters acetone extract was mixed with 3 mL hexane, and then 8 mL water was added to separate carotene into the hexane layer. Absorbance at 475 nm was measured to calculate total carotenoid content by using a value of 2500 for the extinction coefficient (E1%) (Britton, 1991).

For anthocyanin analysis, a 5-g slurry sample was taken and homogenized with 30 mL 1% hydrochloric acid. Absorbance at 530 nm was measured to calculate total anthocyanin content as cyanidin-3-glycoside (Fuleki and Francis, 1968). If the absorbance was over 1.0, the sample was diluted with 1 % hydrochloric acid.

Total Sugar Content

Five grams slurry was collected and homogenized with 30 mL 80% ethanol. The extract was cleared by storage at -20℃ for several days, and the upper layer was used for HPLC analysis. The HPLC system consisted of a binary pump (Perkin Elmer LC 250, Norwalk, CT), an autosampler (LC 200), a refractive index detector (LC 25), and a 700CH carbohydrate analysis column (Alltech Associate, Deerfield, IL) with a guard cartridge (Hamilton et al., 1998). A 20 μL sample was injected with water as the solvent, at a flow rate of 0.5 $mL \cdot min^{-1}$. Column temperature was maintained at 90℃. Sugar concentrations were calculated using standard curves of sucrose, glucose, and fructose. Total sugar content was calculated by summing the sucrose, glucose, and fructose contents.

Statistical Analysis

Experiments were conducted as randomized designs with three replicates. Each treatment had three bags as an experimental

unit for the sliced or whole carrots, respectively. Means and standard errors were calculated, and the means were separated using Duncan's multiple-range test at $P < 0.05$.

Results and Discussion

Visual Observation

The sliced carrots maintained color and other visual quality throughout the experiment, although there was some whitening on the cut surface after 2 weeks in storage. The whitening or discoloration was a common problem in the minimally processed carrots. Formation of lignin has been reported as a healing process of wounded tissues (Cisneros-Zavallos et al., 1995; Howard and Griffin, 1993). However, no off-flavor caused by microbial growth or decay was observed in the sliced carrots during storage at 2℃ or 4℃ for 4 weeks. The whole carrots were also stored without any loss of visual quality and development of off-flavor.

Total Carotenoid Content

There was little reduction in the total carotenoid content at 2℃ during 4 weeks in storage in either the sliced or whole roots of purple and orange carrots (Fig. 1). However, there was a slight reduction in carotenoid content at 4℃ storage during the same time. After transfer from 2℃ to 4℃ at day 14, the changes trended toward those stored at 4℃ continuously. Given that 2 weeks are generally accepted as the commercial marketing period, there was little or no reduction in the total carotenoid content when carrots were stored at 2℃, 4℃, or in the 2-4℃ transfer storage.

Sliced carrots contained about 10-15% less total carotenoid than whole roots during storage for 4 weeks. A decrease in carotenoids in sliced carrots may be a result of more rapid oxidation due to the increased surface area and respiration due to cutting damage. Chen et al. (1996) reported that the carotenoids in carrots consist of highly unsaturated molecules that are subject to isomerization which causes color loss and oxidation, lowering the nutritional value of the carrot when stored. A reduction of 14-18% in carotenoids in the first 3 days was similarly observed in minimally processed carrots (Howard and Dewi, 1996).

Total carotenoid content of purple and orange carrots was 200-230 μg·g^{-1} fresh weight and 60-100 μg·g^{-1}, respectively. The carotene levels in the purple carrots were somewhat higher than we found in earlier measurements of breeding lines (Lazcano, 1999). Because we have seen great variation due to seed batches of the purple carrots and selective breeding for higher carotene was performed continuously, considerable increase in carotene content was possible. A similar range of carotene content was also reported in processed carrots by Alasalvar et al. (2005). The orange carrot used in this study as a comparison contained about

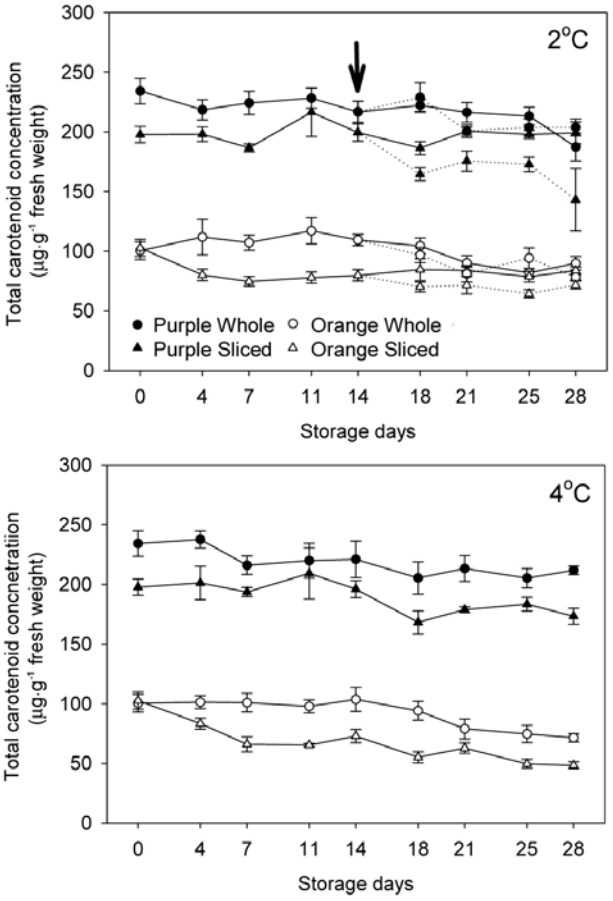

Fig. 1. Changes in total carotenoid concentration of purple 'BetaSweet' and orange carrots stored at 2°C or 4°C for 28 days. Arrow and dotted lines indicate that carrots stored at 2°C were transferred to 4°C at 14 days. The vertical bars represent standard errors.

100 μg·g^{-1} fresh weight carotenoids initially. We noticed the purple carrots contained higher levels of carotene than most of the orange carrots in our breeding lines, but some orange carrots may have higher carotene content, depending on the source.

Total Anthocyanin Content

Anthocyanin content in the purple carrots was unchanged or slightly increased in all treatments over the 4 week storage period, except under the transfer treatment (from 2 to 4℃ at 14 days), where anthocyanin content gradually decreased in the sliced carrots after 3 weeks (Fig. 2). The initial anthocyanin content ranged from 370-400 μg·g^{-1} fresh weight in either the whole or sliced purple carrots. Anthocyanins in black or purple carrots have higher color stability than anthocyanins from other plants, which has been attributed to the presence of acylated groups (Downham and Collins, 2000). The chemical structure of six anthocyanins from similar black carrots was previously reported (Glassgen et al., 1992) and the general composition was found to be similar to the purple carrots (data not presented).

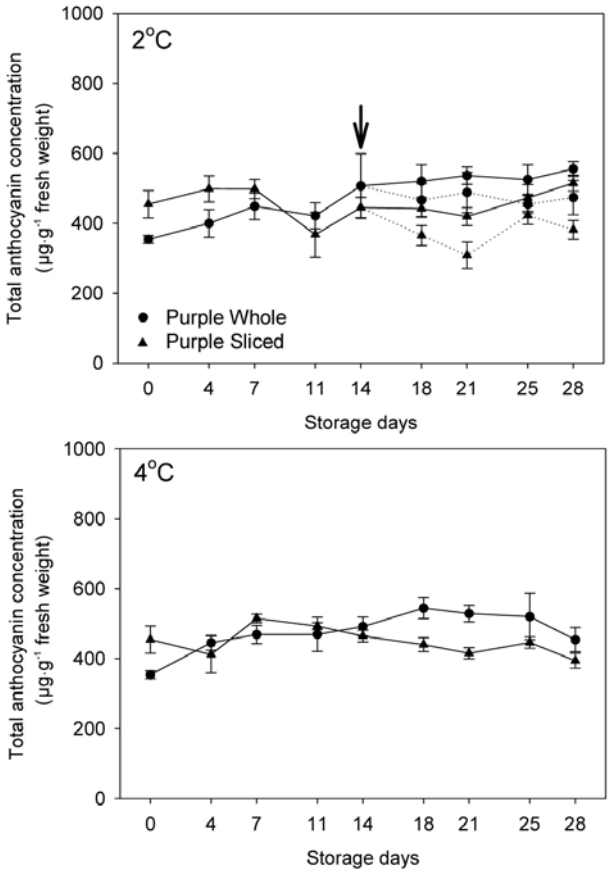

Fig. 2. Changes in total anthocyanin concentration of purple 'BetaSweet' carrots stored at 2°C or 4°C for 28 days. Arrow and dotted lines indicated that carrots stored 2°C were transferred to 4°C at 14 days. The vertical bars represent standard errors.

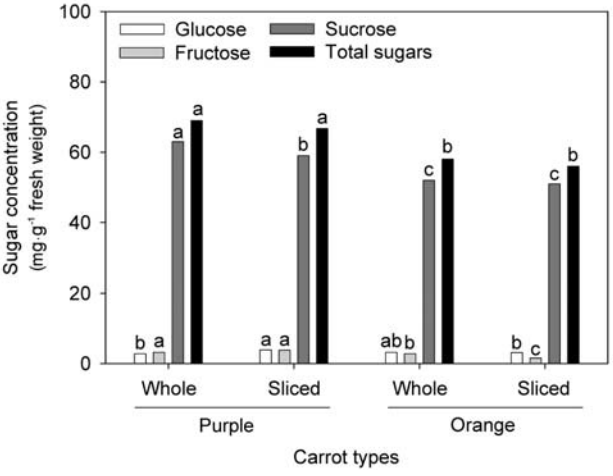

Fig. 3. Sugar concentration of purple 'BetaSweet' and orange carrots. Means of each sugar with different letters are significantly different according to Duncan's multiple-range test at $P < 0.05$.

Total Sugar Content

Our data showed that the purple carrots contained slightly higher total sugar content than the orange carrots (Fig. 3).

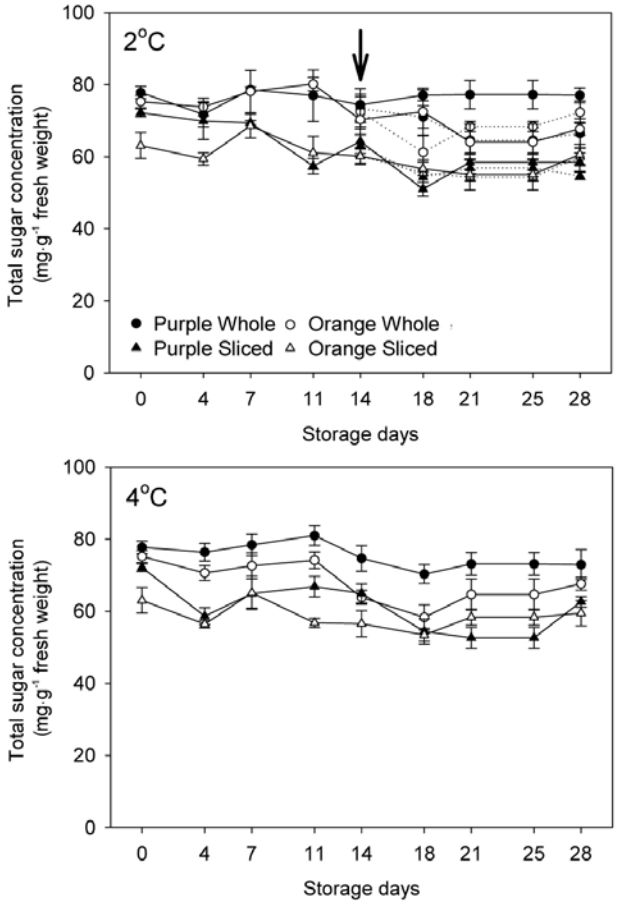

Fig. 4. Changes in total sugar concentration of purple 'BetaSweet' and orange carrots stored at 2°C or 4°C for 28 days. Arrow and dotted lines indicated that carrots stored 2°C were transferred to 4°C at 14 days. The vertical bars represent standard errors.

The total sugar content was about 70 mg·g^{-1} fresh weight in purple carrots and about 60 mg·g^{-1} in the orange carrots. Sucrose was the major sugar in both carrots, representing about 90% of total sugar content, with glucose and fructose below 10 mg·g^{-1} fresh weight. There were no differences in the total sugar content between the whole and sliced carrots in the purple and orange carrots.

During storage, the total sugar content slightly decreased or remained the same after 2 weeks (Fig. 4). Storage temperature had no observed effect on total sugar content for all carrots during storage at 2℃, 4℃, or after transfer from 2℃ to 4℃ during the 4-week testing period (Fig. 4). From these results, we have concluded that the sugar changes in the sliced carrots were minimal and did not present a problem.

Effect of Harvest Dates on the Quality of Whole Purple Carrot

Ensuring the same quality during different harvest dates based on maturity is very important in maintaining product quality in minimally processed vegetable products. In this

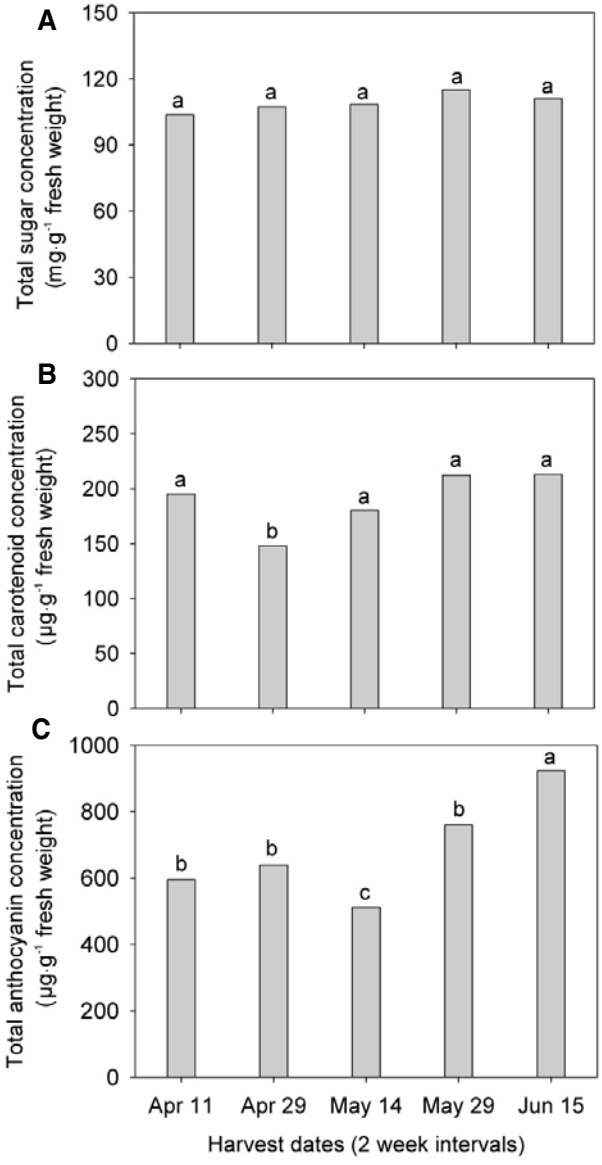

Fig. 5. Total sugar (A), carotenoid (B), and anthocyanin (C) concentration of whole purple 'BetaSweet' carrots by harvest dates. Means of each compound with different letters are significantly different according to Duncan's multiple-range test at $P < 0.05$.

study, we confirmed that the nutritional quality of raw carrots was consistent or slightly increased during the season (Fig. 5). Total sugar content did not change significantly, but there did appear to be a trend to slight increase (Fig. 5A). Total carotenoid content was maintained at similar levels, except one harvest date, due to either sampling error or location of harvest (Fig. 5B). Anthocyanin content showed an increasing trend over the harvest times (Fig. 5C), for unknown reasons. There was a tendency towards increase in carotene, sugars, and anthocyanin content by maturity in our preliminary studies (Lazcano, 1999). However, maturity, location, or other factors influencing the quality of carrots were out of the scope of this study.

Storage temperatures at either 2℃ or 4℃ had little or no influence on changes in nutritional content, measured as total carotenoids, anthocyanins, and sugars during storage for 4 weeks. Initially, sliced carrots contained slightly less total carotenoid, anthocyanin, and sugar than whole carrots, but these levels remained unchanged during storage. This reduction was thought to be due to fast-oxidation and respiration caused by cutting damage. We tested for 4 weeks and found no significant reduction in the nutritional components at 2℃ or 4℃ storage, or after the transfer condition for 2 weeks. Thus, we concluded that cold chain marketing at 2℃ or 4℃ for 2 weeks was suitable for purple 'BetaSweet' and orange carrots for maintaining their quality and marketability. Because there was no reduction in quality during harvest dates over a 2-month period in the spring, consistent quality product of sliced purple carrots can be supplied to consumers.

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